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FAO Fisheries Technical Paper No. 121
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CONTRIBUTION TO A WORLD-WIDE INVENTORY OF EXOTIC MARINE AND ANADROMOUS ORGANISMS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 1973

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SAST	Datos relativos a ciertas especies y poblaciones
MAST	Sinopsis sobre métodos y materias
OT	Sinopsis sobre oceanografía
IT	Sinopsis sobre limnología

y

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CB	Listas de periódicos, secciones especiales de la «Aquatic Sciences and Fisheries Abstracts (ASFA)», bibliografías especiales y trabajos relativos a los problemas de documentación
MFS	Ediciones provisionales de los «Manuales de la FAO de Ciencias Pesqueras»
WAFR	Reseñas provisionales de los recursos pesqueros y de su estado actual de explotación, por regiones o por grupos de especies, en el marco del sistema mundial para la evaluación de los recursos pesqueros

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FAO Fisheries Technical Paper No. 121
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CONTRIBUTION TO A WORLD-WIDE INVENTORY

OF EXOTIC MARINE AND ANADROMOUS ORGANISMS

by

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Rome, November 1973

PREPARATION OF THIS DOCUMENT

This review paper was originally prepared as a working document for submission to the Sixth Session of the Advisory Committee on Marine Resources Research (ACMRR) in 1971, in implementation of a request from SCOR that the scientific aspects of transplantation, particularly its biological and ecological implications, be reviewed in view of the wide scientific interest in the subject.

The present revised version has been prepared in response to a recommendation of the ACMRR Sixth Session that the review be given wide dissemination throughout the world to meet the information requirement of the scientific community. As well as other inventories the FAO Fishery Data Centre (FDC) will maintain the present inventory and up-date it as and when more data on the subject are made available to the Fishery Resources Division of the Department of Fisheries.

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Exotic marine and anadromous organisms - world. Algae, Porifera, Hydroidea, Polychaeta, Sipunculida, Echinodermata, Mollusca, Crustacea, Ascidiacea, Pisces. Distribution - geographic records. Introduction, acclimatization, environmental effects. Selected bibliography.

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1. FOREWORD

People of many maritime countries have deliberately introduced exotic marine animals to their coasts from time to time, and for a variety of reasons: to enrich their local fauna with fish or invertebrates that are more valuable or more prolific or otherwise more desirable as food, game or bait than the native species; to replace species that have become depleted by over-fishing or by natural causes; to fill what have appeared to be unoccupied ecological niches.

Sentiment has often been a driving force behind the urge to establish exotics. Voyagers returning home have sought to enrich their homelands with some of the living wonders of the countries they visited. Colonists have tried to make things more home-like by bringing familiar creatures to the shores of their adopted lands. Aquarists, reluctant to kill their unwanted live specimens often discard them into natural areas, and the organisms, their lives thus humanely spared, sometimes survive to reproduce and establish populations.

By far the largest number of exotic marine species, especially of invertebrate animals and algae, have become introduced to their new homes unintentionally, attached to the shells of oysters imported for cultivation, and on the hulls or in the water ballast of ships. Some of these stow-aways which are native to tropical or sub-tropical regions have been able to survive in temperate or cold localities where the water is heated artifically by the effluents of power plants or factories.

The removal of biogeographical barriers, most notably the opening of the Suez and Panama Canals, has permitted passage of some marine organisms between seas.

Few introductions are well documented. In the past, deliberate introductions have rarely been preceded by adequate ecological surveys to provide a basis for estimating before the fact, or of measuring afterward, the impact of the new species upon the native biota.

During the last third of the 19th century, when acclimatization of plans and animals enjoyed widespread popularity, special acclimatization societies and government bureaus gave much attention to the practice. Many introductions at that time were accompanied by a great fanfare of publicity sometimes with optimistic claims of immediate success, followed by a dead silence afterward.

We have gathered the material for this study from published literature and by correspondence. In the beginning we had planned to organize it geographically, by appropriate sections of the globe, but found such large gaps of information about different areas that it seemed preferable to present the material according to the preceding outline.

In a previous version of this article entitled "Introduction of Exotic Marine, Euryhaline and Anadromous Organisms - A Preliminary Review", issued by FAO (ACMRR 6/71/WP2 Oct. 1970), we wrote:

> "Because of the fragmentary nature of the available material, we call this a preliminary review, with the hope of stimulating marine biologists to send us such records as we have omitted, so that we may present something approaching the comprehensive geographical study to which we had aspired."

We sent copies of that version to biologists in all the maritime countries, and received a number of corrections and additions. These we have included in the present version.

No doubt there still remain many omissions of records which we hope that others will fill in future such compilations.

2. INTENTIONAL INTRODUCTIONS

2.1 The skaros Sparus cretensis. The Earliest Recorded Introduction of a Marine Fish.

We include this record because of its antiquity. As far as we know, it recounts the first experiment in transplanting a marine fish from one area to another.

The ancient Greeks and Romans wrote more about the skaros (Gr.) or scarus (L.) than any other fish. They discoursed extensively about its natural history, methods of catching it and about the tenderness, delicacy, sweetness and digestibility of its flesh. It was most abundant and of best quality in the Carpathian Sea, i.e. that part of the Aegean between the island of Karpathos and Asia Minor. Evidently it was uncommon if not a rarity on the Italian coast. Pliny (ix.29) wrote that it never, of its own accord, passed from the Carpathian Sea beyond Lectum, the southwestern promontory of the Troad, i.e. the territory of ancient Troy. Columella, on the other hand, said that it seldom passed beyond Sicily. No matter which of the two was right, the skarus seems to have been not easily available to the Romans.

Consequently, in the first century A.D., Optatus Elipertius, the commander of the fleet under the emperor Claudius, had large quantities of this fish transported from the Carpathian Sea and distributed in various places along the Italian coast between Ostia and the region of Campania. For five years the skaros was carefully protected, all caught being required to be returned to the sea. "Since then", said Pliny, "they have always been found in great abundance off the shores of Italy, where formerly none had been taken previously. Thus has gluttony introduced these fish to be a dainty within our reach, and added a new inhabitant to our sea ...."

Pliny completed his Natural History about 25 years after the introduction of the skaros to the Italian coast. He and Columella may have been correct in limiting the original distribution of the species to the Aegean Sea. If so, the transplant was a success. Some 1800 years later, Günther (1862) gave the distribution of this species as "eastern and western parts of the Mediterranean, Madeira, Canary Islands". Jordan (1887), on the other hand, referring the species to Sparisoma cretense, remarked that it was rather rare in the Mediterranean Sea. More recently, Ben-Tuvia (1966), calling it Euscarus cretensis, says that it is "common in the Mediterranean". An FAO publication cataloguing fish names, published in 1960, lists this species, giving its modern vernacular names used in Spain, France, Greece, Italy, Malta, Turkey and Yugoslavia. Tortonese writes (private communication, 1970) "S. cretense is now quite a common fish all along the coast of North Africa". Whether the ancient Roman transplanting experiment accounts for the present relatively wide distribution of the species must remain unanswered.

2.2 Shad

The colonization of shad (Alosa sapidissima) from the Atlantic coast of the United States to the Pacific coast ranks among the most remarkable achievements of fish acclimatization. This anadromous member of the herring family ranges naturally from rivers tributary to the Bay of Fundy region to the St. Johns River in Florida. Shad spend most of their lives in the sea. The sexually mature fish enter rivers in spring or early summer and swim far upstream to spawn. Shortly after spawning the spent fish return to salt water and the fry proceed downstream soon afterwards. Shad migrate hundreds of miles at sea, but generally return to their home streams to spawn.

Shad fry were transported across the United States and planted in the Sacramento River, California, in 1871, 1873, 1877, 1878 and 1880; and in the Columbia River between Oregon and Washington in 1885 and 1886. The total number put into each stream was less than one million.

The first shad returning from these plantings was caught near San Francisco in 1873; the species had become numerous by 1879, and one of the most abundant food fishes of the State by 1886. In 1876 or 1877 shad were taken in the Columbia River, evidently having migrated there from the California plantings. By 1882, the species reached Puget Sound; and nine years later the first fish was recorded from the Fraser River in British Columbia

and another from the Stikine River in southeast Alaska. In 1904, one was taken at Kaselof, on Cook Inlet, Alaska. Meanwhile the species worked its way southward, eventually going as far as the Mexican border. Within three decades the shad had not only firmly established itself but extended its range along about 4,000 miles of the Pacific coast. By 1914, the commercial catch of shad had risen to its peak of 7 million pounds; it has since declined to fluctuate around 2 million pounds. This quantity may not reflect the true abundance, for the shad is said to be not fully appreciated as a food fish.

2.3 Striped Bass

Eight years after the first shad was transported from the Atlantic to the Pacific, another anadromous Atlantic species was similarly introduced, the striped bass Roccus morone of the family Serranidae. In 1879, 132 young specimens shipped from New Jersey were planed in San Francisco Bay; and in 1882 a second lot from the same source was deposited in about the same place. From these 435 fish, few though they were, grew a large population. The species now extends its ranges as far north as the Columbia River and as far south as southern California. Before 1935, the commercial catch of striped bass fluctuated between about half a million to a million pounds annually. After 1935 striped bass became almost exclusively restricted by legislation to sport fishermen. Thanks to careful management of the resource, the sport catch has been stable at about 1.5 million fish since 1942 (Neave, 1954). Plantings of striped bass have been made since in many parts of the world, but with no remarkable success.

A recent attempt to introduce this species to another region far distinct from its native home, was made in 1965. Then 50 thousand two-day old larvae were shipped by air from a hatchery on the Roanoke River to Moscow, U.S.S.R. Of the total received, 100 fish survived to reach a length of 3 cm. A subsequent shipment was sent for rearing to the Chernorechenskoe Trout Station; and of these 200 fry were grown successfully to a size of 15.35 cm, and planted at the mouth of the Khipska River on the Black Sea shore of the Caucasus (Bogdanov, Doroshev and Karpevich, 1967). We have not yet learned the results of this experiment.

2.4 Salmons and Trouts

Salmonids have been transported for acclimatization more extensively than any other group of fishes. This family, peculiar to cold and temperate regions of the northern hemisphere, includes the Atlantic salmon and the trouts (Salmo), the chars (Salvelinus) and the Pacific salmons (Oncorhynchus). These fishes have various degrees of attachment to fresh water. At one extreme are two species of chars (Salvelinus oquessa and S. aureolus) and the Great Lakes trout (Cristivomer namaycush). At the other extreme are at least two species of Pacific salmons, the pink (Oncorhynchus gorbuscha) and the chum (O. keta); and perhaps also the king (O. tshawytscha), which must reside for some time in a marine environment either to reproduce or to establish and maintain a natural population. Between these two extremes the species are capable of adapting to land-locked situations, or, where they have access to the sea, of being anadromous. Some individuals may spend their entire lives in rivers (cf. Rounsefell, 1958).

Pacific Salmons. It is the Pacific salmons that are most abundant and the object of the greatest fisheries. The world commercial production in 1965 was over 400,000 tons, as compared with 12,000 tons of Atlantic salmon and 24,000 tons of trouts and chars.

Since 1872 many attempts have been made to introduce Pacific salmons (Oncorhynchus) to various parts of the world, in the hope of developing new fisheries.

The five principal species of this valuable genus are the chinook salmon (O. tshawytscha), the sockeye or red salmon (O. nerka), the coho or silver salmon (O. kisutch), the chum or dog salmon (O. keta), and the pink salmon (O. gorbuscha). These are native to the temperate and arctic waters along both American and Asian coasts of the North Pacific. A sixth species, O. masu, occurs only on the Asian side. The native distribution of Oncorhynchus is confined almost entirely to the temperate and arctic waters of the North Pacific (Davidson and Hutchinson, 1938). All of the species are anadromous. The adults of all die after spawning. After a period in fresh water the young salmon descend their home rivers to live in the ocean. As they approach maturity they return, usually to the streams of their birth, to spawn and

die. This life history pattern is common to all species of Pacific salmons. It differs in several important details between species, and, in some degree, within species - for example the rates of growth, longevity, duration of time spent in fresh water and in the ocean and location of the spawning grounds with respect to distance from the sea. Spawning takes place over clean gravel beds or pockets among the rocks. In rivers it is confined usually to comparatively shallow areas where the current is swift, and in the lakes to areas where the water is kept flowing by seepage or surface drainage. The temperatures of the streams in which salmons have been found spawning range from slightly above 0° to 21°C. The eggs incubate during the winter at temperatures between 4° and 11°C, though they can survive short intervals outside these limits. After hatching, the optimal temperature for growth and survival of the young ranges between 13° and 17°C. In the North Pacific Ocean, salmon have been taken between the North American and Asian coasts in water cooler than about 15°C. This particular combination of fresh water and ocean conditions necessary to the survival of the Pacific salmons, occurs in few other regions. Nevertheless, attempts have been made to introduce one species or another to various localities along the Atlantic coast of North America from Canada to Louisiana; and to waters of Mexico, Nicaragua, Brazil, Argentina, and Chile; Hawaii, New Zealand, Australia and Tasmania; and Norway, England, France, Germany Netherlands, and Italy (Vinciguerra, 1893, 1896; Davidson and Hutchinson, 1938; Ripley, unpubl rept.).

Most of these experiments, which were conducted with chinook, sockeye, pink and coho salmons, were unsuccessful, usually because physical properties of river or sea environments in the areas of introduction were unfavourable to the stocks introduced. In northeastern America, runs of silver and pink salmons became established in rivers of Maine, New Brunswick and Ontario; but these were far too small to support fisheries. In the southern hemisphere, a sea run population of chinook salmon large enough to support a small fishery developed in South Island, New Zealand. Runs of sockeye and coho salmons also developed in Chile. Whatever be the quantities taken for market either in New Zealand or Chile, they are too small to be reported in the FAO Yearbook of Fishery Statistics (1968).

In the 1930's, the Soviet Union attempted to transplant chum salmon (O. keta) from the Amur River to Barents and White Sea areas. These experiments were not successful. The effort was resumed in 1956 and has continued since then (Isaev, 1961). The species chosen were the pink salmon (O. gorbuscha) and the chum (O. keta) because the young leave the rivers earlier than do the young of Atlantic salmon and therefore will not seriously compete with that species for food during the river period of life. The pink salmon has an added advantage in that its life cycle is only two years. Eggs used for transplantation were collected in Sakhalin and Kamchatka where the temperature regimens are most nearly like those of the Barents Sea region. Between 1957 and 1960, about 39 million fry and fingerlings of pinks were released in the Kola, Umba, Ura, Kanda, Birma, Luvenga and Nira rivers and in Kandalaksha Bay; about 10 million fry and fingerlings of chum salmon were released in the Kola and Ura rivers.

In July 1960 mature pink salmon began to approach the coast and enter rivers for spawning in many rivers[1/] which empty into the Barents and White Seas, not only those into which they had originally been planted. More than 10,000 pink salmon were accounted for from the young fish released in 1959. Spawning was observed in a number of rivers.

1/ Entry of pink salmon was observed in the following rivers: Pochema (79), Titovka (364), Bolshaia Zapadnaia Litsa (478), Ura (236), Tuloma (313), Kola (218), Teriberka (62), Voronia (2), Varzina (13), Iokanga (247), Kachkovka (30), Ponoi (11,547), Pialitsa (11,826), Chapoma (25,117), Strelna (1,135), Tetrino (320), Chavanga (4,487), Varzuga (1,828), Varzuga (in the sea, 4,150), Kashkarantsa (38), Kuzreka (630), Umba (4,520), Umba (in the sea, 906), Poriia (in the sea, 1,136), Kolvitsa (376), Niva (150). Pink salmon also entered rivers of the Karelian coast of the White Sea; the Kem, Pongom, Vonga, Gridina and Keret, into the rivers of the Winter and Summer coasts of the White Sea and also into the Pechara, Onega, Mezen, Kuloi, Severnaia Dvina, Soina, Indiga and Oma.

Fishermen took pink salmon in 1960 along the Norwegian coast between Kirkenes and Froms; and also in southern Norwegian waters down to the coast near Namsos. Fish entered some Norwegian rivers to spawn. One specimen was captured near Aberdeen, Scotland, another in the River Derwent, near Workington, Cumberland (Hardy, 1961), and 12 off the coast of Iceland. Evidently, the "homing instinct" of the transplanted fish had become lost. Most of the eggs of pink salmon deposited on the spawning grounds in the Barents and White Sea areas in 1960 died, probably owing to the sharp fall in water temperature during the period before eye pigmentation (Persov, 1966). In 1958 and 1959 about the same numbers of young were released as in 1957. However, the numbers of adults returning to spawn were lower. While there were hundreds of thousands in 1960, there were thousands in 1961 and less than a thousand in 1962. Thus there has been great variation in survival of the introduced salmon. It will be most interesting to follow the further development of these experiments which have continued (Karpevich and Lokshina 1965 and 1967, Karpevich and Lukonina 1968, 1970 and 1971).

The Atlantic salmon (Salmo salar), and several species of trouts have been introduced around the world, generally in the interest of sport fishing. The Atlantic salmon is native to the North Atlantic basin, ascending all rivers of northern Europe and those of North America north and east of Cape Cod, its northern limit being about Lat. 50° N and southwest Greenland (Jordan, Evermann and Clark, 1950). We have found early records of attempts to establish this species of eastern North America south of its natural range (Smiley, 1884), and in rivers of western North America (Smith, 1896), Argentina (Tulian, 1908) and Tasmania (Francois, 1965). During the second half of the 19th century Italian zoologists made experimental plantings of Atlantic salmon into some lakes of northern and southern Italy. These attempts were all unsuccessful. There were doubtless many attempts to establish it in other places.

Introductions of trouts, principally the brown trout of Europe (Salmo trutta) and the rainbow trout of western North America (Salmo gairdnerii) have been remarkably successful. The range of the brown trout, for example, originally confined to Europe and North Africa now includes all continents except Antarctica. Sea-run brown trouts occur in northeastern North America from northern New Jersey to Newfoundland; and also in Tasmania and New Zealand (Scott, 1964). If commercial fishing for these exotic sea-run trouts is permitted, the production is too small to be recorded in the FAO Yearbook of Fishery Statistics (1965): nor have we found any quantitative records of sport catches.

2.5 Sturgeons

Sturgeons of various stages, from egg to young adult, have been transplanted between bodies of water in the U.S.S.R., for example, the sterlet (Acipenser ruthenus) from the Ob River to the Amur River, in 1967, the Russian sturgeon (Acipenser güldenstädti) from Gur'yevsk Sturgeon St. (presumably a hatchery) to the Ural River, and the Baikal sturgeon (A. baeri baicalensis) from the Talanga River to the Gulf of Riga fish plant. (Karpevich and Lukonina, 1971).

During the 1960's scientists of the U.S.S.R. introduced two species of sturgeon into the Baltic Sea, Acipenser güldenstädti, native to rivers flowing into the Black and Caspian Seas, and A. baeri native to Siberian rivers and to Lake Baikal. From the limited information available, it appears that the plantings were made chiefly in the innermost part of the Gulf of Finland, in Riga Bay and in the surrounding waters. (Otterlind, 1970). A number of young specimens (presumably of the original lots planted) have since been taken along the Finnish south and west coasts as well as along the Swedish east coast. Since these species do not mature until about ten years old, it is still too early (1971) to judge the success of the introductions.

2.6 A North Pacific Greenling

Rass (1970) discusses the considerations involved in the transplantation of a species of greenling Pleurogrammus monopterygius (family Hexagrammidae) from southeastern Kamchatka to the Murman coast, as follows :

"The absence of Hexagrammidae in the North Atlantic apparently stems from historical factors that prevented the spread of greenlings here rather than from a difference in current life conditions of the fish in this area. Hexagrammidae are undoubtedly capable of existing in the northern seas of the Atlantic and adjacent seas of the Arctic Ocean. Purposeful human intervention could supplement the fauna of these seas with Hexagrammidae.

Naturally it is only worthwhile acclimatizing the most promising species, i.e. the most valuable fish in taste and abundance which form schools that are easy to catch. For acclimatization, consideration should be paid to the presence of an appropriate niche (a free biological place) in the water body. It is also necessary to take into account the interrelationships between the species that are introduced and the native fauna, a predator which could be harmful should not be admitted, nor should the introduction of any accompanying parasites be permitted. A theory of acclimatization was worked out by Zenkevich (1952) and later by Karpevich (1960). The basic necessity for acclimatization, in the author's opinion, is the presence of a free, appropriate biological place for the introduced species (in other words, a suitable biotope) and appropriate abiotic conditions.....

In 1958..... eggs (of Pleurogrammus monopterygius) were collected off southeastern Kamchatka and were transferred by airplane to the Murman coast. Incubation of the eggs and release of the larvae were carried out at the Murmansk Marine Biological Institute at Dal'nie Zelentsy ..... Transfer of the eggs and incubation were most successful. In September 1958 viable larvae hatched out and were released in the sea (Orlov and Polikashin, 1962)".

2.7 Introductions of Salmons, Sturgeons and Molluscs in the U.S.S.R.

In a summary of data on introduction of fishes into bodies of water in the U.S.S.R. during 1957, Karpevich and Lukonina (1971) list the following items which are pertinent to the present compilation. They cite previous lists by Karpevich and Bokova (1963), and Karpevich and Lokshina (1965).

Basic Data on the Transplantation of Fishes in the USSR in 1967

Bodies of water		Month of introduction	Material for introduction	
Parental waters	Stocked waters		Stage	Quantity thousands
	Family Acipenseridae			
Sterlet [Acipenser ruthenus L.]				
Kuybyshev res.	Ozerna res.	X	v.a.	1.2
Ob River	Amur River	XI		0.24
Russian sturgeon [Acipenser güldenstädti Brandt]				
Gur'yevsk sturgeon st.	Ural River	V-VII	y.	853.8
Baikal sturgeon [Acipenser baeri baicalensis A. Nicolsky]				
Selenga River	Gulf of Riga	VI	eggs	250.3
	Volgograd f.p.	VI	"	249.6
	Family Salmonidae			
Pink salmon [Oncorhynchus gorbuscha (Walbaum)]				
Sakhalin f.p. and Kamchatka f.p.	Onega f.p. (Murmansk coast rivers)	X	eggs	6000.0
Karachi River	Barents Sea basin	X		835.0
Sokolova f.p.	Onega f.p.	X		4182.4
Bereznyakovo f.p.	"	XI		1589.4
	Invertebrata Class bivalvia			
Monodaena colorata (Eichwald)				
Sea of Azov (Gulf of Taganrog)	Kuybyshev res.	VI		126.1
" "	Aral Sea	VII		276.0
Lower reaches of Don	L. Balkhash	VIII		114.0

2.8 Oysters

Moving oysters about from one place to another has been going on in Europe since ancient times. Pliny (Book IX, Chap. 79) speaks of transplanting oysters from Brundisium, at the southern extremity of Italy to Lake Lucrinus for fattening, Lake Lucrinus in Campania which was famous among the ancient Italians for the excellent flavour of its oysters, has since been filled by a volcanic eruption. Pliny (Book XXXII, Chap. 21) speaks also of importing oysters from Britain to Italy. According to the translator's footnote "Varro speaks of those (oysters) of Tarentum as being the best. The Greeks preferred the oysters of Abydos; the Romans under the Empire, those of Britain". (Bostock and Riley, 1855).

The oyster of the Northwestern Atlantic (Crassostrea virginica) is distributed along the Atlantic and Gulf coasts of the United States and Canada and the West Indies. It can survive through winters in places where the prevailing temperature is as low as 1°C, and through summer, where it reaches as high as 36°C; but it can spawn only in water of at least 15°C. Mass spawning of an oyster population is more likely to occur in water higher than 22° to 23°C (Galtsoff, 1964). Even though the temperature requisite to spawning of Crassostrea virginica be met, as in its native range, the set of larvae fluctuate greatly according to subtle conditions of environment. Since this oyster is comestibly excellent, it has been shipped regularly to some other parts of the world to augment the supply of native species, even after experience has proved that it cannot become established. Thus beginning in the last part of the 19th century it was introduced to the Pacific coast of North America, where the native oyster Ostrea lurida, though also a delectable species, is too small to satisfy the market demand.

The first lot of C. virginica intended for acclimatization was shipped by railroad from the east coast of the United States in 1870 and planted in San Francisco Bay. Subsequent lots were introduced into Puget Sound and Willapa Bay, Washington. Although the oysters failed to establish populations in these localities, more were continually brought in to grow and fatten for market. Experience was similar in British Columbia, where C. virginica was introduced into Boundary Bay, and Esquimalt and Ladysmith Harbors. Although seed were successfully grown to marketable size in Boundary Bay, the mortality was too high to justify continuing the practice, and instead 3 or 4-year old oysters were brought in for a year to grow before marketing. There was even some reproduction in the estuaries of the Serpentin and Nicomek Rivers, which flow into Boundary Bay. By 1930 a population on the bars had grown to about 5000 bushels but it has not prospered and by 1969 only a few specimens were to be found (Quayle, 1969). C. virginica has also been introduced into a number of European localities. In the winter of 1879-80 one million spat and five thousand adult oysters from the United States were planted in ten different points in the Little Belt of the Baltic Sea (Möbius, 1883). Three years later the oysters were still alive but there was no evidence of their spawning. Möbius wrote that he would attempt another introduction of this species, this time from New Brunswick, Canada, where the temperature of the water in summer is more like that of the Baltic. However, we have found no record that such an attempt was made or that there were any further introductions of North American oysters into the Baltic following those of 1879-80. C. virginica has also been introduced into British waters but only to supplement the large summer market demand. Apparently, the species has not become established in Britain. On the other hand, introduction into Hawaii in the last decade of the 19th century resulted in establishing a spawning population there (see section on Hawaii).

The European flat oyster, Ostrea edulis, native from latitude 65°N in Norway to Morocco, and into the Black Sea as far as the Crimea, was introduced to the coast of Maine in 1949 and to New Brunswick, Canada, in 1957 and 1953 and reproduced in both places with some promise of establishing permanent populations (Loosanoff, 1955: Yonge, 1966).

From 1962 to 1965 several lots of the European flat oyster, Ostrea edulis, were transported from Milford, Connecticut, eastern U.S.A., and Arcachon, France, and planted in three localities in California - Tomales Bay, Drakes Estero and Morro Bay. Growth stopped in all survivors after one year. One lot transferred from Tomales Bay to Elkhorn Slough, died within 12 months. Survival was poor in all areas except Tomales Bay. Histological study showed the

oysters to be infested with a parasitic micro-organism of undetermined origin. This, presumably, was responsible for the poor growth and low survival. Although the European flat oysters may have brought the disease with them, the Pacific oysters which were immediately adjacent remained unaffected while specimens of Portuguese oysters became infested within two months after exposure to the parasitized flat oysters (Katanskay, et al, 1969). It seems likely that the flat and Portuguese oysters had been brought into an area where there was a local pathogen to which they were susceptible and to which the Pacific oyster was immune.

The Portuguese oyster (Crassostrea angulata) was introduced into France many decades ago and developed large natural beds in the estuaries of the Gironde and the Charente rivers (Yonge, 1966). About 1870, a ship with Portuguese oysters on board sank at Arcachon, France, in the Bay of Biscay. The oyster survivors established a colony which became a regular source of supply (Orton, J.H., 1937). Portuguese oysters were also brought into England for relaying; but there they reproduce only occasionally during abnormally warm summers. The same species was introduced into Knysna Lagoon, South Africa, about 1954 to start an oyster farm. The experiment was "not very successful", (J.H. Day, personal letter).

In Japan, Professor Takeo Imai at the Oyster Research Institute at Karakuwa, Kesennuma City, Miyagi Prefectura, Japan, cultivates Ostrea edulis from Marennes, France, and O. lurida from the State of Washington, U.S.A.; also a scallop, Patinopecten vessoensis, native to Hokkaido and vicinity, and an abalone, Norditis discus, native to northern Japan. According to Imai (1967), "The characteristic of the method is that the larvae, juveniles and adults are cultured continuously and thoroughly under a float in the sea. The floating culture equipment is set in Mohne Inlet connected with Karakuwa Bay which is open to the Pacific Ocean. The inlet is well sheltered and never gets rough even in a storm." The cultivated species established naturally reproducing populations.

The Japanese oyster Crassostrea gigas was introduced (Hanna, 1966) into waters of the west coast of the United States between the late 19th and early 20th centuries. Presumably oysters in a shipment of adults sent from Japan to Washington for market sometime during that period had spat attached to their shells, which survived the transportation across the ocean. These must have been thrown overboard with the shucks onto a shallow water bed where they grew (Cahn, 1950). During subsequent years, spat of C. gigas has been shipped to various parts of the west coast of the United States and planted. Although they have survived and grown to adult size, temperatures in many localities along the North American western coast are warm enough in only a few localities during the few necessary days to permit reproduction. Reproduction has been reported for Puget Sound, Hood Canal and Willapa Bay, Washington, and Newport Bay, California. A small race of this oyster from Kumamoto Prefecture, Japan, has been introduced into waters of Washington State, as well as in Drakes Estero, Elkhorn Slough, Morro Bay and Salton Sea in California.

In Canada the species was planted in Ladysmith and Penden Harbors, Baynes Sound and Boundary Bay. It spawned and produced a sizeable spatfall in 1932. Since then spawning has been sporadic, resulting in only seven commercial sets in 23 years. Heavy settling occurred in 1936, 1942, 1958 and 1961 (Quayle, 1964).

The same species of Japanese oyster, Crassostrea gigas, was brought to Australia in 1947 and 1948 during November when water temperatures of the original and receiving locations were compatible. As much as 825,000 seed oysters were shipped in 1947, and 750,000 in 1948. About 30 percent of these survived, and were planted into Pittwater (Tasmania) and Oyster Harbor (south coast of western Australia). Although they survived in Pittwater with little loss and grew sixfold during the first year, those in Oyster Harbor all died, perhaps owing to a scarcity of food and the occurrence of a heavy growth of the alga Enteromorpha in 1948. Spawning occurred in Pittwater during early February in 1949 and again in 1950 and during January 1951. In each case the spawning started when the water temperature had risen above 22°C. Thomson (1952) concludes that the size of the brood stock is important for achieving a rapid increase in the population of C. gigas.

Willson (1970) reports further on this introduction as follows: "The original site (of the introduction) at Midway Point near Hobart, in southern Tasmania, proved unsatisfactory

and the brood stock was moved to Port Sorell, on the northern coast where the environment proved more suitable. The oysters spawned and showed every indication of becoming established but an attempt to farm them commercially failed and the project was abandoned. Left to their own devices the oysters thrived and their spat was carried by tidal currents 20 miles eastward to Tamar River..... Adult stocks were also released in the river and this may have contributed to the spread of the oysters. The first signs of oysters were noted in the Tamar about 1955. They multiplied rapidly, and within 10 years they could be seen on rocks and wharf piles for 30 miles up the river. The waters of the Tamar River appear to be free of predators and diseases which attack oysters. The only damage reported has come from mud worms which retard the oyster's growth."

Regarding a New Zealand oyster transplanted to Tasmania, Dartnall (1969) writes, "Introduction of oysters, Ostrea angasi (Sowerby 1871) to bolster a failing industry and satisfy public demand is mentioned in the Fisheries Department Reports (1885, 1887) and the Report of the Sea Fisheries Board (1926-27). New Zealand oysters were imported for sale at the Hobart Fish Market, where they were kept alive in crates in the water, from about 1920 onwards. Commercial import of oysters from the Bluff, South Island, New Zealand, continued into the 1930's, the oysters being carried as deck cargo aboard the ships operating the 'Horseshoe Run' which ran regularly between the Bluff and Hobart. Towards the end of the 1930's commercial import of oysters appears to have ceased, but the crews would carry oysters as deck cargo, shucking the oysters as the ship entered the Derwent Estuary and throwing the detritus overboard before the ship docked....." Thus a number of other invertebrate species were evidently unintentionally introduced. (See 5.4).

The lack of suitable records usually makes it difficult to measure the net benefit of introducing exotic oysters into a region where there is already a commercially valuable native species. Fortunately, production records for Washington and Oregon, U.S.A., go back to 1892 when the Eastern Pacific or Olympic, oyster (Ostrea lurida) was the only commercially valuable species. That was the year when its harvest was at its highest peak. Then the eastern oyster (C. virginica) was already being transplanted to California for fattening. By 1933 spat of the western Pacific, or Japanese, oyster (C. gigas) was being transplanted to all three states and the adults harvested, as shown in the following table. Because reproduction of this species on the west coast is sporadic, the transplanting must be carried on continuously. As a commercial operation it is evidently more profitable than harvesting the native species or transplanting the eastern American one.

	O. lurida			C. virginica			C. gigas		
	1892	1933	1968	1892	1933	1968	1892	1933	1968
	(Thousands of pounds of meats)								
Washington	1979	220	57	-	1	-	-	2791	6418
Oregon	15	4	1	-	-	-	-	25	628
California	294	1	-	1022	58	16	-	27	646
TOTALS	2288	225	58	1022	59	16	-	2843	7692

3. THE HAWAIIAN ISLANDS

The Hawaiian Islands provide the best documented example of a poor native marine fauna which has been enriched by judicious introduction of exotic species. The Hawaiian Islands are one of the most isolated archipelagos in the world. Judging from the pattern of Pacific Ocean currents, the endemic marine fauna is derived from the western tropical Pacific. It appears to be composed chiefly, if not entirely, of species whose life histories include a long enough infant period of drifting in the pelagic zone to permit transport from their distant points of origin. Being so limited, the Hawaiian fauna is conspicuously lacking in

many species of aquatic fishes and invertebrates which would prosper in Hawaiian waters had they the means of making the journay.

For example, there are no purely fresh-water fishes in Hawaii, and among marine species no snappers of the genera Lutjanus and Lethrinus. There are only two species of groupers (Epinephelus), and two of sardine-like fishes in Hawaii, as compared with 22 and 8 in two other islands of eastern Oceania. This depauperate situation applies to the aquatic fauna in general, including food fishes as well as molluscan and crustacean shellfishes. Thus it appeared logical that the variety and perhaps also the abundance of fishery resources could be enriched by the introduction of exotic species.

Gosline and Brock (1960) group Hawaiian marine habitats into three categories (1) sublittoral or reef, (2) pelagic, and (3) benthic. With one exception, the introduced marine species have been of the sublittoral region, i.e. between the surf line and a depth of 50 meters; including some local reefs, rocky and sandy areas, and admixtures of these. According to Brock (1960) some estuarine habitat is present at the mouths of some streams, and in harbors, such as Pearl Harbor, Honolulu Harbor, Port Allen, and Hilo.

Some 30 species of marine and euryhaline animals had been intentionally introduced into Hawaiian waters. By 1960, 13 of these had become established residents, 8 showed some promise of becoming established, and 9 had not become established. By 1969 Brock (personal communication) added five species to the established list, including the giant prawn, Macrobrachium lar, which he had not mentioned in the 1960 paper, and the Japanese oyster, Crassostrea gigas, which he had previously believed to be definitely not established. He wrote "there has been no evidence of a damaging impact of these exotics on the native biota. The fresh-water reservoirs lack native fishes in any case and the reef environment is one of high diversity and low relative abundance of any particular species. I doubt that further introductions could alter that situation; it is more true of the sources of the introduced reef fishes where species diversity is greater than in Hawaii."

Following is Brock's partial list of marine and euryhaline species introduced into Hawaiian waters as of 1969. It does not include fortuitous introductions of smaller invertebrates, or aquarium fishes which may have been introduced without intent to establish them.

Species	Open Sea	Reef	Estuary	River
(1) Established Species				
Tapes philippinarum			x	
Cytherea meretrix			x	
Crassostrea gigas			x	
Crassostrea virginica			x	
Scylla serrata			x	
Macrobrachium lar			x[1/]	
Sardinella marquesensis	x		x	
Mollienesia latipinna			x	
Limia vittata			x	
Tilapia mossambica			x	
Cephalopholis argus		x		
Lutjanus kasmira		x		
Lutjanus vaigiensis		x		

1/ Larval stages live in brackish or sea water; adults in fresh water streams

Species	Open Sea	Reef	Estuary	River
(2) Did Not Establish				
Ostrea lurida			x	
Crassostrea amasa		x	x	
Crassostrea commercialis			x	
Pinctada martensii			x	
Tivela stultorum		x 2/		
Tridaena crosea		x		
Anchoa compressa	x		x	
Oncorhynchus tschawytsha				x
Roccus saxatilis	x		x	x
(3) Introduced Species That May Become Established				
Haliotis cracherodii		x		
Cephalopholis urodelus		x		
Epinephelus merra		x		
Epinephelus hexagonatus		x		
Epinephelus spiniger		x		
Epinephelus fasciatus		x		
Lutjanus gibbus		x		
Lutjanus guttatus		x		

2/ Sand beaches

The following notes are taken almost entirely from Brock's 1960 paper and his 1969 letter.

I Established Introduced Species

MOLLUSCS

1. Japanese clam; also called Damon clam, Tapes philippinarum. First recorded introduction consisted of ten barrels of specimens, imported in 1920 from Japan and planted in Pearl Harbor, Hawaii, and in Kaneohe and Waialae Bay, Oahu. Descendants of the original plantings were subsequently introduced into other bays of the Hawaiian Islands. The species became well-established and has prospered sufficiently to supply a steady market demand.

2. Japanese clam, sometimes also miscalled "Pismo Clam", Cytherea meretrix. In 1926 some 10 gallons of these clams were brought in from Japan and planted in Kaneohe Bay and off Kalihi, Oahu. In 1939 a second lot of 20,000 small seed clams from Japan were planned in Kaneohe Bay and Mokapu, Oahu. This species is well established on Oahu and possibly on other islands also.

3. Northwestern Atlantic oyster, Crassostrea virginica. Attempts to introduce this valuable oyster of eastern North America in 1871 and 1883 were apparently unsuccessful. In 1893, 1000 were brought in from San Francisco and two years later an additional 38,614. Both of these lots were planted at Manana, Ewa, in Pearl Harbor on Oahu and resulted in establishing the species in Pearl Harbor. While there were subsequent shipments they apparently did not contribute to its further establishment in Hawaii. In recent years oysters taken from Pearl Harbor have been

planted at localities on Kauai, Molokai, Maudi, and Hawaii. By 1969 this species had become common in Kaneohe Bay in the upper part of the tidal zone on rocky surfaces.

CRUSTACEA

4. Giant prawn, Macrobrachium lar. This species, native to Guam, was brought to Hawaii, reared in ponds, and introduced about most of the Hawaiian Islands. It has become well established in some stream systems. Although the adults live in short, clear-water streams, the larval stages require brackish or sea water to survive. The females grow to be 3/4 pounds, the males over two pounds. They are amenable to cultivation and considered a fine delicacy.

5. Samoan crab, Scylla serrata. This large crab occurs in salt water swamps and mangrove areas over a vast area extending from Africa and India through tropical Asia and Polynesia. Each year between 1926 and 1935 a few crabs were brought from Samoa. During that period a total of 98 crabs were released into Hawaiian waters. The largest number brought in during a single year was 23 (introduced in 1932) and apart from the introductions during 1932, which were on the Hilo coast of Hawaii, all the others were at various localities on the coast of Oahu. Today this crab is common in the waters of all the major islands of Hawaii. It is valued as food and brings a good price in the local markets.

FISH

6. Marquesan sardine, Harengula vittata. The Marquesan sardine, the first species of a purely marine fish established in Hawaiian waters by transplantation, was introduced from the Marquesas Islands by the U.S. Fish and Wildlife Service (Murphy, 1960). This was done to establish a species that would be suitable bait for the tuna fishery. Between 1955 and 1957 about 144,000 fish were released in a series of plantings at various localities around the Island of Oahu.

Small numbers of Marquesan sardines caught in the fall of 1956 were probably fish of the 1955 planting. Beginning in the late summer of 1958, however, some of the fish captured were too small to be derived from any of the original introductions. Although up to that time, all catches were from Oahu, many of the late ones were small fish from Kauai, Maui, and Hawaii, indicating growth and distribution of a population. The large plantings made in 1957 and early 1958 may have provided a sufficient stock of fish to establish the species.

7. Roi, Cephalopholis argus. In 1956, 571 were brought to Hawaii, from Moorea, Society Islands. These fish were given a prophylactic treatment of copper sulphate for 5 days and then planted in two lots: 171 off Browns Camp, Oahu, and 400 off Keahole Point, Hawaii. By 1969 this bass was well enough established on the reefs to be occasionally taken by fishermen.

8. Taape, Blue-lined snapper, Lutjanus kasmira. Five specimens were brought from the Marquesas Islands and held in captivity at Coconut Islands, Kaneohe Bay, Oahu. In 1958, 2,435 were released in Kaneohe Bay from a shipment originating in the Marquesas Islands. By 1969, this species had become common enough in some areas to provide catches of 50 pounds or more.

9. Toau, Lutjanus Vaigiensis. In 1955, 50 specimens from the Marquesas Islands were held captive at Coconut Islands. In 1956, 239 from Moorea, Society Islands, and in 1958, 23 from the Marquesas Islands were released in Kaneohe Bay, Oahu. By 1969 this snapper was common in some areas and well regarded by fishermen.

10. Sailfin, Mollienesia Latipinna. The sailfin, a species useful for mosquito control, was introduced in 1905 from Seabrook, Texas, and established initially at Moanalua, Oahu. It is now well established in brackish water areas of Oahu and Molokai.

11. Top minnow, Limia vittata. This species, useful for mosquito control, is found in the streams flowing through Honolulu which include Moanalua, Capalama Canal, Nuuanu, and Manoa streams. It is also found in the lower portion of the streams and in salt water. The origin and date of introduction are not known.

12. Tilapia, Tilapia mossambica. In 1951 some 60 small tilapia were sent to Honolulu from Singapore. Of the original shipment, all but 14 subsequently became diseased and died. The 14 survivors bred in the laboratory tanks of the Fish and Game Division and their offspring were used for stocking purposes. This species has been useful for four purposes in Hawaii: (1) as live bait for tuna fishing; (2) as a means of controlling certain aquatic plants in irrigation systems; (3) as a food fish - modest quantities are sold in local markets; and (4) for sport fishing - tilapia provides good fishing especially for youngsters. It is well established on all of the major Hawaiian Islands.

II Species which showed some promise in 1960 but which had evidently not become established by 1969

Although many of the following species could be taken or seen in a wild state at the time of Brock's writing in 1960, their introductions were still recent and there was no evidence that they had successfully reproduced. Brock felt that some of these would probably become established and others would not.

INVERTEBRATE

1. Black abalone, Haliotis cracherodii. In August 1959 and again in September of that year 728 black abalones from southern or Baja California were planted off Pyramid Rock, Oahu. In a subsequent check of the first Pyramid Rock planting, some 19 abalones were found moribund and some 20 apparently in excellent condition. The survivors seemed to be those which were able to find adequate shelter. These were small abalones 2.5 to 7.5 centimeters in shell diameter.

FISH

2. Nato, Kuhlia rupestris. A shipment of 43 specimens was received from Guam in 1957 and held in Fish and Game Laboratory tanks. In 1958 another shipment of 170 was received and 104 of this shipment were subsequently planted in a small stream at Bellows Field, Oahu.

3. Rero, Cephalopholis urodelus. Eight released off Browns Camp in 1958 were part of a shipment from the Marquesas Islands.

4. Tarao, Epinephelus merra. In 1956, 132 of this species imported from Moorea, Society Islands, were released at Wainini, Kauai, and 469 at Kaneohe Bay, Oahu.

5. Grouper (no local common name), Epinephelus spiniger. Some 22 specimens, brought from the Marquesas Islands in 1958, were released at Browns Camp, Oahu.

6. Matapuu, Epinephelus fasciatus. In 1958, 51 specimens from the Marquesas Islands were released off Browns Camp, Oahu.

7. Tarao a'au, Epinephelus hexagonatus. In 1956 some 113 specimens from Moorea, Society Islands, were released off Keoncoio, Maui.

8. Tuhara, Lutjanus gibbus. In 1958, 40 specimens from the Marquesas Islands were released in Kaneohe Bay, Oahu.

9. Spotted rose snapper, Lutjanus guttatus. In May 1960, about 3,000 spotted rose snappers from Manzanillo, Mexico, were released in the lees of Ilio Point, Molokai, and 400 more in Kewalo Basin, Oahu.

4. THE BERMUDAS

The Bermuda marine fauna, a depauperate branch of the West Indian fauna, is derived mostly from the Bahamas, probably largely through the agency of floating seaweed (Verill, 1902, 1908; Beebe and Tee-Van, 1933). Considering fishes, it includes, for example, only a third to half of all the snappers (Lutjanidae), jacks (Carangidae) and sea basses (Serranidae) which are common on reefs and along shores in the subtropical and tropical parts of the

western Atlantic. Moreover, some pelagic species, for example the bluefish (Pomatomus saltatrix) which reach Bermuda only sporadically via the Gulf Stream, fail to establish endemic populations there.

Some time during the 1920's, Mr. Louis L. Mowbray and others introduced 13 marine species into Bermuda waters with a view to establishing populations suitable for commercial and game fishing. Five of these were temperate water fishes of the western Atlantic transitional zoogeographical zone, namely the winter flounder (Pseudopleuronectes americanus), black sea bass (Centropristes striatus), scup (Stenotomus chrysops), northern kingfish (Menticirrhus saxatilis), and tautog (Tautoga onitis). The remaining eight were typical West Indian species. These were the mutton fish (Lutjanus analis), dog snapper (Lutjanus jocu), grey grunt (Haemulon plumieri), porkfish (Anisotremis virginicus), spadefish (Chaetodypterus faber), grey angelfish (Pomacanthus arcuatus), French angelfish (Pomacanthus paru), and queen angelfish (Pomacanthus ciliaris).

According to Mr. Mowbray, only three of the 13 species have survived. The queen angelfish is well established and becoming more abundant each year. The grey angelfish is less abundant and caught only occasionally. The mutton snapper also provides an occasional catch; one weighing 25 pounds was taken about two years ago. In 1942, 300 spiny lobsters were brought in from the west coast of Africa and planted. Eight years later two were caught, but none has been seen since. Although clams and oysters were introduced from the east coast of the United States, non survived. (Mr. Louis Mowbray, personal conversation with Mr. David Hansen of New Jersey).

5. UNINTENTIONAL INTRODUCTIONS

5.1 Introductions via Canals

A. The Suez Canal. Since the opening of the Suez Canal a century ago, a number of marine species have crossed over from the Red Sea and colonized in the Mediterranean. Some Mediterranean species may have negotiated the passage, but the consensus seems to be that few, if any, have been able to establish in the Red Sea.

According to Thorson (1968) almost 9 times as many species of Red Sea animals seem to have traversed the Canal during the last 40 years as during the preceding 60 years. This is owing to changes in hydrographic properties of the Canal water, notably a diminution of salinity in the Great Bitter Lake.

Calman (1927) observed that among 16 species of crabs that he collected during the 1924 expedition to the Suez Canal, only two had come from the Mediterranean, and they had not passed beyond the Timsah Lagoons. Of the 14 Red Sea species 4 had reached the Mediterranean and had successfully established there. One of them, Neptunus pelagicus, was being fished commercially at Alexandria and Haifa. The other three were pebble crabs which are too small to be of direct value to man, but may have additive effect in the food pyramid. These are Heteropanope laevis, H. vauquelini, and Eucrate crenata.

Steinitz (1967) compiled records from various sources, accepting them at their face value without verifying the species identification. At the time of his writing, he planned a critical evaluation and an amended list to be published later. His 1967 paper on immigrants via the Suez Canal lists 130 species of organisms, including algae, invertebrates of several phyla, and fishes. Assuming all the identifications to be correct, only 12 percent of the species in Steinitz' list were Mediterranean forms that had been collected in the Red Sea (see Table 1).

Ben Tuvia (1966) found no fishes of Mediterranean origin in any of the extensive Red Sea collections of Israel; nor had N.B. Marshall (1952). Neither did Clark and Gohar (1953) mention any Mediterranean immigrants in their studies of Red Sea fishes. Ben-Tuvia (1966), critically considering the records of several authors, concluded that while few, if any, Mediterranean fishes have established themselves in the Red Sea, at least 24 Red Sea species have established in the Mediterranean. Ben Tuvia considers only four of these to be rare in the Mediterranean - a round herring Etrumeus teres, mullet Liza carinata, swellfish

Sphaeroides spadiceus, and sand gurnard Platycephalus indicus. At least five are common enough to be of noteworthy commercial value: a barracuda Sphyraena chrysotaenia, a jack Atule djeddaba, a goatfish Upeneus moluccensis, a rabbitfish Siganus rivulatus and a lizard fish Saurida undosquamis. At least two are important in the food web, a soapy Leiognathus klunzingeri, and a silverside Pranesus pinguis.

Tortonese (1970) has reported the arrival into the Mediterranean of Siganus luridus, a species common in the Red Sea. It was spreading westward, and by 1968 had reached Libya.

TABLE 1

FROM RED SEA TO MEDITERRANEAN
[Steinitz, 1967, modified by Tortonese. Private com. 1971]

PLANTS

Algae
Cladophoropsis zollingeri (Kutz) Børg

Cormophyta
Halophila stipulacea (Forssk.) Asch.
[Dr. Tortonese says this may be an old inhabitant of the Mediterranean]

ANIMALS

Porifera
Halichondria viridis (Keller)
Didiscus placospongoides Dendy

Hydroidea
Pennaria disticha australis Bale
Filellum serratum (Clarke)
Leptochela pugnax De Man
Palaemonella vestigialis Kemp
Periclimenes calami Tatt.
Automate branchialis Holth. & Gottl.
Alpheus audouini Coutière
A. crassimanus Heller
A. rapacida De Man
Synalpheus hululensis Coutière
Ogyrides mjöbergi (Balss)
Myra fugax (Fabricius)
Leucosia signata (Paulson)
Ixa monodi Holth. & Gottl.
Notopus dorsipes (L.)
Charybdis hellerii (A.M. Edw.)
C. longicollis Leene
C. merguiensis De Man
C. sexdentata (Herbst)
Thalamita poissonii (Aud.)
Neptunus pelagicus L.
N. sanguinolentus (Herbst)
Pilumnopeus vauquelini (Aud.)
Pilumnus hirsutus Stimpson
Atergatis rossus (Rüpp)
Eucrate crenata De Haan
Hyastenus hilgendorfi De Man
Platimaia wywillethompsoni Miers
Plagusia tuberculata Lam.

Polychaeta
Sullis exilis Grav.
Opisthosyllis brunnea Lgh.
Nereis zonata persica Fauv.
N. capensis Willey
Perinereis nuntia Sav.
Pseudonereis anomala Grav.
Dasychone cingulata Grube
Rhodine loveni gracilior Tauber
Asychis gotoi Izuka

Sipunculida
Aspidosiphon elegans (Cham. & Eyscnh.)

Arthropoda

Copepoda
Pseudodiaptomus salinus Giesbr.
Temora discaudata Giesbr.
Canthocalanus pauper Giesbr.
Calanopia elliptica (Dana)

Amphipoda
Elasmopus pectenicrus (Bate)
Stenothoe gallensis Walker

Cumacea
Eocuma sarsii (Kossm.)

Decapoda
Penaeus japonicus Bate
P. semisulcatus De Haan
Metapenaeus monocerus (Fabricius)
M. stebbingi Nobili
Trachypenaeus curvirostris (Stimpson)
Leptochela aculeocaudata Paulson

Stomatopoda
Squilla massavensis Kossmann

Pycnogonida
Anoplodactylus saxatilis Calman

Mollusca
Pteria occa Reeve
Meleagrina albina Lam.
Chama broderipii Reeve
Malleus regulus Forssk.
Mytilus variabilis Krauss
Hippopus hippopus L.
Mactra clerina Phil.
Paphia undulata Born.
Arca rufescens Reeve
Fulbia australia Sow.
Clementia papyracea Gray
Murex ponderosus Sow.
Cerithium erythraeonense Lam.
C. scabridum Phil.
Cypraea moneta L.
Conus arenatus Hwass.
Fusus marmoratus Phil.
Murex tribulis L.
Pirenella caillaudi P. & M.
Diodora rueppellii Sow.

Echinodermata
Asterina WEGA Perr.
Amphioplus laevis Lym.
Ophiactis savignyi Müll. Trosch.

Ascidiacea
Herdmania momus (Sav.)
Ascidia cannelata (Sav.-Oken)
Phallusia nigra Sav.
Symplegma viride Herdm.
Metrocarpa nigrum (Herdm.)
Ecteinascidia moorei Herdm.

Pisces
Aprionodon brevipinna (Müll. Henle)
Himantura uarnak (Forssk.)
Dussumieria acuta Val.
Etrumeus teres (De Kay)
Saurida undosquamis (Richards)
Hemirampus far (Forssk.)
H. marginatus Forssk.
Parexocoetus mento (Val.)
Aphanius dispar (Rüpp.)
Holocentrum rubrum (Forssk.)
Sphyraena chrysotaenia (Klzgr.)
Pranesus pinguis (Lac.)
Liza carinata (Ehr.)
Apogon
Upeneus moluccensis (Blkr.)
U. asymmetricus Lachn.
Atule djeddaba (Forssk.)
Leiognathus klunzingeri (Steindchnr.)
Siganus rivulatus (Forssk.)
S. Luridus (Rüpp.)
Callionymus filamentogus C.V.
Platycephalus indicus (L.)
Dollfusichthys sinus-arabici (Chab.)
Stephanolepis diaspros Fr.-Br.
Sphoeroides spadiceus Richards

FROM MEDITERRANEAN TO RED SEA

P L A N T S

Algae
Acetabularia mediterranea Lam.
Hyalodiscus stelliger Bailey

A N I M A L S

Porifera
Leucandra aspera O. Schmidt
Euspongia zimocca (O. Schmidt)
Plecortis simplex F.E. Schulze

Sipunculida
Phascolion strombi (Montag.)
Aspidosiphon mülleri (Diesing)

Crustacea

Amphipoda
Chelura terebrans Philippi

Pisces
Engraulis enchrasicholus (L.)
Dicentrarchus labrax (L.)
Serranus cabrilla (L.)
Umbrina cirrosa (L.)
Argyrosomus regius
Solea vulgaris Quensel
Syngnathus abaster Risso

TABLE 2

DATA ON RED SEA FISHES IN THE MEDITERRANEAN
[Adapted from Ben Tuvia, 1966]

English Common Name and Scientific Name 1/	Notes	Occurrence in Eastern Mediterranean	Habit	Geographical Distribution			
				Indo-Pacific	Red Sea	Suez Canal	Mediterranean 2/
Squirrelfish Holocentrum rubrum		Common	Inshore-pelagic	+	+	-	Aegean Sea
Barracuda Sphyraena chrysotaenia	Small quantities caught commercially by purse seiners, trawlers and beach seines. Average yearly catch by Israeli fishermen about 20 tons	Very common	Inshore-pelagic	+	+	+	Anatolia
Silverside Pranesus pinguis	Most common atherinid fish along coast of Israel. Of little commercial importance	Very common	Inshore-pelagic	+	+	+	Anatolia & Libya
Mullet Liza carinata		Rare	Inshore-pelagic	+	+	+	Egypt
Cardinal Fish Apogon nigripinnis	Caught occasionally in Mediterranean near bottom in depths up to 50 meters	Common	Sub-littoral	+	+	+	Israel
Jack Atule djeddaba	Large numbers caught occasionally with gill nets and light fishing	Very common	Inshore-pelagic	+	+	+	Israel
Soapy Leiognathus klunzingeri	One of the commonest bottom species in eastern Mediterranean; often caught in great numbers by trawlers in depths up to 100 meters. Valueless commercially, but important in food web	Very common	Demersal	+	+	+	Aegean Sea; Lampedusa
Goatfish Upeneus moluccensis	Considerable quantities taken by trawl fishery in depths up to 80 meters	Very common	Demersal	+	+	+	Aegean Sea

TABLE 2 (cont'd)

English Common Name 1/ and Scientific Name	Notes	Occurrence in Eastern Mediterranean	Habit	Geographical Distribution			
				Indo-Pacific	Red Sea	Suez Canal	Mediterranean 2/
Goatfish Upeneus asymetricus	Common in shallow waters, but not in commercial quantities	Common	Sub-littoral	+	?	?	Anatolia
Dragonet Callionymus filamentosus	Appears often in beach seines and trawl catches in depths up to 100 meters	Common	Demersal	+	+	+	Israel
Shortfin Shark Carcharhinus brevipinna	Origin questionable; may be from western Mediterranean-Atlantic. Sizes up to two meters often taken by fishermen	Common	Inshore-pelagic	+	+	-	Israel
Whip Ray Himantura uarnak		Common	Demersal	+	+	+	Anatolia
Round Herring Dussumieria acuta	Common in shallow coastal waters. Yearly catch by purse seines (fishing with lights) and trawls (in 30-50 meters does not exceed 50 tons)	Very common	Inshore-pelagic	+	+	+	Anatolia
Round Herring Etrumeus teres	Very rare; probably immigrated recently.	Single record	Inshore-pelagic	+	+	-	Israel
Lizard Fish Saurida undosquamis	Uncommon on coast of Israel until 1955, when appeared in trawl catches. By 1956 was common trawling grounds of Mersin and Iskenderun, Turkey. Average yearly catch for Israel from 1956-1962 was 262 tons	Very common	Demersal	+	+	+	Anatolia
Halfbeak Hemiramphus far		Common	Inshore-pelagic	+	+	+	Aegean Sea

TABLE 2 (cont'd)

English Common Name and Scientific Name 1/	Notes	Occurrence in Eastern Mediterranean	Habit	Geographical Distribution			
				Indo Pacific	Red Sea	Suez Canal	Mediterranean 2/
Flying Fish Parexocoetus mento	Very common along Mediterreanean coast of Israel. Has been collected from Rhodes and from Gulf of Sidra (Libya), indicating remarkable westward migration in Mediterranean	Common	Inshore-pelagic	+	+	-	Aegean Sea; Gulf of Sidra
Killifish Aphanius dispar		Common	Sub-littoral	+ 3/	+	+	Israel
Rabbitfish Siganus rivulatus	Of some commercial importance, being taken in gill nets, trammel nets, beach seines, and on hooks	Very common	Sub-littoral	+ 3/	+	+	Aegean Sea, etc.
Rabbitfish Siganus luridus	Less common than Siganus rivulatus	Common	Sub-littoral	-	+	-	Israel
Sand Gurnard Platycephalus indicus	Single specimens occasionally caught in trawls	Rare	Demersal	+	+	+	Israel
Tongue Sole Dollfusichthys sinusarabici	A bottom fish found frequently among trawl fishes at depths up to 150 meters	Common	Demersal		+	+	Israel
Filefish Stephanolepis diaspros	Common in coastal waters, occasionally to 80 meters deep	Common	Demersal	+ 4/	+	+	Anatolia etc.
Swellfish Sphoeroides spadiceus	Often caught by Israeli trawlers on Anatolian coast of Turkey	Rare	Demersal	+	+	+	Aegean Sea

1/ Common names not given by Ben Tuvia
2/ Farthest point of distribution
3/ Indian Ocean only
4/ Persian Gulf only

B. The Panama Canal. The Panama Canal has provided a passage-way through Middle America between the Atlantic and Pacific Oceans since 1914. It is a lock canal, rising to an elevation of about 85 feet above sea level. A 40-mile stretch of fresh water in the lakes that form part of the canal appears to be the principal barrier to a marine species crossing from either side. Should any species succeed in crossing, a difference of water temperature might affect the success of its establishing, for owing to upwelling, the minimum temperature from February to April on the Pacific side is about 4°C colder than on the Atlantic.

Unfortunately, the marine fauna of tropical America were not well enough known at the time of the opening of the Canal to provide a baseline for evaluating the exchange. For example, it was not until nine years later that the first volume of a monograph on the marine fishes of Panama was published (Meek and Hildebrand, 1923-28).

In 1935 and 1937, Hildebrand (1939) collected fishes and invertebrates in the locks and lakes of the canal, and found a number of species that had moved only part of the way through from both ends.

The only species that had made the complete crossing by 1937 is the tarpon, Tarpon atlanticus. According to Hildebrand (1937), specimens "have been reliably reported from the Pacific terminus of the Canal." And sixteen years later, Farrington in his book "Fishing the Pacific" (1953) said: "There is tarpon fishing in some of the rivers flowing into the Pacific and this species also is taken in Panamanian and Columbian waters."

Several species of fishes that inhabit fresh and brackish water crossed from one slope to the other. Four of these were guavinas or fresh water gobies, two or three crossing from the Atlantic slope to the Pacific, Dormitator maculatus, Leptophilyphus fluviatilis, and probably Eleotris pisonis, and one, Gobiomorus maculatus from the Pacific to the Atlantic.

A silverside, Melaniris, which lives in fresh and brackish water, had reached the lower chamber of Miraflores Locks by 1937; and in Hildebrand's opinion (op.cit.) this was "presumably a result of a migration from the Atlantic to the Pacific slope through Culebra Cut."

5.2 Introduction by Ships

Ships are the agent for widespread introductions of marine organisms, especially sessile forms. These might become transported as fouling organisms attached to hulls; but the most likely mode of travel is in young stages as passengers in ballast tanks or as adults under the grids covering sea inlet valves (Naylor, 1957a, 1965). The tremendous increase in the volume of shipping during the second world war, perhaps also the increase in speed of ships, seems to coincide with the appearance of many species of exotic fouling organisms in all quarters of the globe. Documentation of such introductions is unavoidably spotty, depending as it does in each instance on a systematic biologist of the right speciality being at the right place at the right time. It depends equally on his collecting one or more specimens of the exotic species, on his knowing that it is indeed exotic, and on his publishing the record. The question of whether or not the species really is exotic depends, of course, on the quality of earlier faunal records.

Barnacles, for example, have become so widely distributed by human activities that it is difficult to trace the history and routes of their transport.

However, thanks to zoologists who are particularly interested in this group of animals, there are a few fairly well-documented examples. It appears that sometime in the early 1940's, a barnacle, Elminius modestus, native to Australasia, established colonies in north-eastern Europe. It was reported first in Chichester Harbor (Bishop, 1947). During the following fifteen years or so, its abundance increased and its distribution spread, perhaps owing to further introductions, so that by 1957 populations had become established in areas favorable to survival of this species, not only on the coasts of the British Isles but also of continental Europe from the Netherlands to Portugal as far south as São Martino do Porto (Barnes and Barnes, 1965; Bishop and Crisp, 1957; Crisp, 1958; Crisp and Southward, 1959).

This barnacle thrives in dirty harbors and shallow muddy estuaries having high summer temperatures where it out-competes other species (Crisp and Chipperfield, 1948). It is less successful on shores that are sandy and chalky, and absent from those subject to considerable wave action. Wherever it is abundant, it seems to affect adversely the growth of planktonic larvae of other benthic animals that breed in summer, including larvae of the oyster Ostrea edulis (Crisp, 1958). The possibility that E. modestus has become established in South Africa is suggested by the finding of a single specimen on an experimental plate at Cape Town in July, 1949 (Sandison, 1950). We have found no further information on the establishment of this species in South Africa.

About the same time another barnacle, Balanus improvisus, was being widely disseminated. This species, which Darwin first described from North and South America in 1854, and which had become established in European waters during the second half of the 19th century, was found on the bottom of ships in southern Australian harbors, where it had not been recorded before. It was found at Bathhurst, the Gambia; Freetown, Sierra Leone; and Lagos, Nigeria (Bishop, 1951). It reached Japan some time before 1957 (Utinomi, 1966). "Since this species is now becoming injurious to the cooling water circuits of factories in Yokkaichi, it will do similar harm in other seaside industrial towns. Oysters in Lake Hamana and the pearl culture industry in Ago Bay will also suffer from this noxious animal (Kawahara, Tatuo, 1963).

In 1947, a barnacle of the western Atlantic, Balanus eburneus, whose original range was Boston, Massachusetts, to the West Indies, was found on the hulls of two vessels trading between the Mediterranean and the United Kingdom and of two others returning to the U.K. via the Mediterranean from the Far East. It was also found in Paris on edible mussels supplied from Marseille (Bishop, 1951); and it was reported in Japan in 1964 (Utinomi, 1966).

Another barnacle, Balanus amphitrite amphitrite, a native of the tropical Pacific, appeared in Japan sometime before 1940, where it has become very common (Utinomi, op. cit.). It was also transported to San Francisco Bay (Utinomi, 1960).

The hydroid Hydroides norvegica was new to Australia in 1885 and was seldom seen during the 1920's; but in 1953 it was the most important fouling organism in the Port Jackson area. Sometime later H. norvegica was introduced to New Zealand from Australia. Other species introduced to Australasian waters are: Bugula fla ellata, a fouling organism from the Atlantic and Mediterreanean which now ranges from Eden north to Port Stephens, New Zealand; the British nudibranch Thecacera pennigera, found in Sydney Harbor; the barnacle Balanus algicola, an addition to Australian fauna from Southwest Africa; the hydroid Bougainvillia ramosa, which first appeared in the Watson's Bay area about 1918; the European shore crab Carcinides maenas, found in Victoria; and massive forms of the encrusting Zoovia schizoporella unicornis, believed to have been brought into Australian harbors on two small captured Japanese vessels (Allen, 1953). A fouling polyzoan, Watersipora cucullata, reached Auckland Harbor, New Zealand, evidently between 1955 and 1959, probably via ship from Australia. This species has been recorded from the "Mediterranean, Red, Arabian, China and Carribean Seas, the Indian Ocean, Gulf of Mexico, South Africa, Brazil, Colombia and the Galapagos Islands. Its origin seems to be unknown." (S. Korman, 1960).

Dr. Isamu Yamazi has sent (by letter, 1970) the following tabulation of accidental introductions to Japanese waters :

Species	Source of Introduction	Recorded	Remarks
Myrtilus edulis	by ship from Europe to Kobe Harbour	1931	very abundant, harmful in coastal waters around Japan
Crepidula fornicata (Slipper shell)	by ship from North America to Tokyo Bay	1968	Pacific coast of middle Japan proper, not abundant
Chloromytilus viridis (bivalve)	perhaps by ship from southern tropical waters	1968	Seto Inland Sea, not abundant
Balanus amphitrite amphitrite	by ship from warm tropical waters	before 1940	very common; harmful. On rocks, bottoms of ships, etc.
Balanus improvisus	by ship from Atlantic coast of Europe or east coast of North America	1957	harmful
Balanus eburneus	by ship from east coast of North America	1964	harmful

Wolff (1954) attributes the occasional occurrence in European waters of the eastern North American crab, Callinectes sapidus, to transport in the ballast tanks of ships. A few specimens have been reported in Denmark, Holland, and southwest France. Several zoologists have reported the occurrence of this species in various parts of the Mediterranean, namely, North Adriatic, Aegean eastern Mediterranean and the Ligurean Sea. (Holthuis and Gottlieb, 1955; Kinzelbach, 1965; Tortonese, 1965) Wolffe, in his 1954 paper, also reported another species, Rhithropanopeus harrisi, as living on piles in the south harbor of Copenhagen. The only few able to survive the winter there were those living in a part of the harbor warmed to 6°C by the waste water from a nearby factory.

Rhithropanopeus harrisi, a brackish water crab, originated on the Atlantic coast of North America. From there it was transported long ago, perhaps by ships, to the brackish waters of the Zuidersee in Holland where it rapidly increased. After 1930 populations of Rhithropanopeus enlarged tremendously along the coasts of Europe. The crab appeared in the estuary of the river Gironde in France and around Caen, a few places along the German coast, near Copenhagen, Denmark, the Black Sea, and also in the Azov Sea, and it occurred for several years also in the Caspian Sea. In 1951, R. harrisi was found to be fairly abundant in Polish waters. At present it occurs chiefly in two sections of the Weichsel Delta (Toten Weichsel and Weichseldurchbruch); and also in Frischen Haff and in the lower course of the Mottlau river near Gdansk. Isolated specimens were also found on the coast of the Bay of Gdansk. (Pautsch, et al., 1969). This species has also been recorded in San Francisco Bay, California and Coos Bay, Oregon.

An Atlantic mussel, Modiolus demissus, was found in San Francisco Bay in 1894. During the next 35 years it spread far on the mud flats and inlets of the Bay. Hanna (1939) says: "No record has been found of its intentional introduction; it probably came with shipments of oysters from the Atlantic seaboard (U.S.A.) where it is common."

An edible shrimp, Palaemon macrodactylus, native to Japan, Korea and the north coast of China, was unintentionally introduced into San Francisco Bay, California, about 1954. In reporting the occurrence of the species in its new home, Newman (1963) suggested that it could have been transported across the Pacific in the salt water system of a ship. By 1957, this species was being taken in the commercial catch of shrimps and was well on its way to establishing an abundant population. Although its distribution in San Francisco Bay overlaps that of the native shrimp Crangon, it occupies a different habitat from that species.

An Asian crab, Ericheir sinensis, was first observed in North Germany in 1912 and is now widespread in European coastal waters (Hoestland, 1955).

Dr. J.H. Day, of the University of Cape Town, writes (in a personal letter) of three species of invertebrate animals introduced accidentally to South Africa as follows :

"Polychaeta: Polydora hoplura introduced to Knysna Lagoon from Europe with the Portuguese oyster Crassostrea angulata about 1954.

Mollusca: Marinula tristanensis, a whelk known in Tristan da Cunha; also occurs on rocky shores near Cape Town.

Crustacea: The Xanthid crab Pilumnoides parlatus common on the cold Atlantic coasts of South Africa. According to Barnhard, K.H. 1950, p. 257, this may have been accidentally introduced from South America."

It is possible that ships may disseminate small fishes as well as invertebrates. Bilge-water transport may explain the introduction of the two Asian gobies into the Sacramento-San Joaquin River, California - one, the yellowfin goby, Acanthogobius flavimanus, native to the estuarine waters of Japan, Korea and Eastern China (Brittan, et al., 1963); and the trident goby, Tridentiger trigonocephalus, native to the coastal waters of China from about Hong Kong and the Northern Philippines northward to Japan, Korea, and the Amur River (Lachner, et al., 1970).

Springer (1963) reported collecting in Trinidad a marine species of blenny, Omobranchus dasson (japonicus) which is native to East Africa, Australia and Japan. This species has since also been collected in Venezuela; and in 1969 Robins found it to be the commonest species around the docks north of Port of Spain (Lachner, Robins, and Courtenay, 1970).

Strasburg (1956, 1966) reported a blenny from Hawaii, Omobranchus alongatus, which is native to East Africa, East Indies, and the Central Pacific. Specimens were taken first from a concrete tank on Coconut Island, Kaneohe Bay, Oahu, and subsequently from an open reef in Pearl Harbor. Strasburg suggested the species could have become introduced in 1951 along with Tridacna clams and other organisms which were obtained from near the Samoan Islands.

Kinzie (1968) reports the occurrence of two species of exotic stomatopods, Gonodactylus falcatus and G. hendersoni, about Oahu Island in the Hawaiian Islands. These could have been transported in concrete barges that were towed there from the area of the Philippines or the South China Sea at the end of the second world war. Collecting on reefs at Waikiki, Kinzie found that G. falcatus was "by far the most abundant stomatopod and G. hendersoni was common in some areas." Ten years before, Townsley (1953) had found the native species Pseudosquilla ciliata to be dominant there (Townsley, 1953). In that intervening decade, the colonists had displaced the natives from one type of habitat where they had been common, namely in coral heads, and limited them to burrows in fine muddy sand and silt, and to areas with a similar substratum but with a great deal of algal growth, chiefly Acanthophora.

A small clinid fish which Fraser Brunner reported as a new species in the Conway estuary was subsequently identified by Wheeler (1958) as Stathmonotus stahii, native to the Caribbean. Wheeler suggested that it might have been transported across the Atlantic by a floating dock in the hold of a dredger or among the fouling organisms of a ship's hull.

Ships are probably the principal agent for disseminating marine algae. For example, the red alga called Falkenbergia rufolanosa, but actually the tetrasporic generation of Asparagopsis armata (Horridge, 1951) is native to southern Australia, Tasmania, and New Zealand. Observed first outside its native range in the extreme south of France in 1923, it spread to the Isle of Man by 1954, and has recently spread extensively in Western Europe and to the shores of the Mediterranean.

Prof. Goran Michanek, of the University of Gothenberg, has written as follows (personal communication, 1969), "The only attempted review I know about (regarding immigrants to

Swedish marine algal flora) is from a few lines in Suneson, Svante, 1953, Algforskningen pa Kristineberg. K. Svenska Vetensk Akad. Arsbok. (The algal research at the Kristineberg Zoological Station). There is no summary; however, I have made a free translation of what might interest you with a few explanations added" as follows :

"The algal flora of the Swedish west coast has been observed for more than a century, which makes it possible to document some changes in its composition. Rare, microscopic or critical species may always have lived in the area, even if they only recently were detected or distinguished. But in some cases we have been able to follow the immigration of new elements in the flora. H. Kylin has shown that Trailliella intricata (the tetraspore stage of Bonnemaisonia hamifera, which has never been found in Sweden or adjacent waters), is now forming dense red wads on coarser seaweed. This species is entirely lacking in old collections from Bohuslän (west coast county north of Göteborg). Nowadays it is one of the most common species in the area. It has spread southwards along the coast of Holland (a coast county south of Göteborg) as shown by Suneson.

The green alga, Codium dichotomum, was not known from our coasts until 1933 when some specimens were found at Krinstineberg by Kylin. It has then spread rapidly along the coast of Bohuslän and can now be considered a characteristic species. On rocky bottoms 1-2 m in depth it often forms a dense crop. Its close relative, Codium fragile, has also been found in Bohuslän, first by T. Levring in 1945. Another immigrant is the brown alga Colpomenia peregrina, found in 1950 by Levring. This was the first finding on the Swedish west coast, but it did not come quite unexpectedly as the species had spread along the European coasts from the south and has recently been reported from Denmark and Norway. In 1953, Dr. R. Santesson found the red alga Dasya pedicellata not far from Kristineberg (unpublished). These species are southern and their appearance may be connected with hydrographic changes. But also the immigration of a species with northern distribution has been recorded. Fucus inflatus (according to Powell Fucus disticus subsp. edentatus) was first found at Fjallbacka in 1924 and then by D.E. Hylmo at Varberg in 1928. Later it was found in several places in the Göteborg region and in some places it is now almost the dominating Fucus species. It is a subarctic species, is found in or around harbours, and is considered to have been brought here with fishing vessels. In the 1950's S. Lund found it as far south as Copenhagen and Malmö."

The green algae Codium fragile tomentosoides presumably native to Japanese waters (Silva, 1955) has become distributed around the world, perhaps with seed oysters from Japan, perhaps in ballast water of ships. It seems to have spread first through the Pacific and then into the Atlantic, reaching Europe sometime around 1900. Here it was observed first in Holland, later in Denmark (1920), Sweden (1938), England (1939), and Norway (1952). By 1957 it had become established on the east coast of North America at Montauk Point, Long Island. By 1962 it had spread to Cape Code, Massachusetts, and by 1966 to Barnegat Bay, New Jersey (Taylor, 1967). This seaweed threatens many valuable beds of clams and oysters and indeed has already smothered many of them to death.

Rosenvinge (1920) reported several species of marine algae introduced into Danish waters, probably by ships. These are Gigartina mamillosa, Trailliella intricata, Codium tomentosum and Codium mucronatum.

A number of exotic aquatic plants that can live in saline water have become established in various coastal areas of North America. Presumably aquarists and private pond culturists are responsible for many of these introductions. The following species have been recorded as exotic by Hotchkiss (1967).

Eurasian Watermilfoil, Myriophyllum spicatum: fresh inland water and fresh to brackish coastal water; California and Wisconsin to Vermont, Texas and Florida. This plant has been in the United States for at least seventy years. Since 1955 it has become very abundant in Upper Chesapeake Bay, the tidal Potomac River, and several Tennessee Valley reservoirs.

Andean Watermilfoil, Myriophyllum elatinoides: a native of South America and New Zealand which has run wild in the Deschutes River near Bend, Oregon.

South American Elodea, Elodea densa (Philotria densa): this common aquarium plant has run wild in fresh inland and rarely in coastal waters from Oregon to Massachusetts, California, and Florida.

Curly Pondweed, Potamogeton crispus: fresh inland water and fresh to slightly brackish coastal water; Alberta to Quebec, California and Florida. This native of the Old World has been in North America for at least 150 years and is still spreading.

Yellow Floating Heart, Nymphoides peltatum: fresh water, inland and rarely coastal; a native of Europe which has run wild in a few localities in Washington, New York, New Jersey, Missouri, Oklahoma, and Arkansas.

A southern Australian alga, Asparagopsis armata, became established in the Mediterrean in 1925 (Svedelius, 1933) and subsequently spread to Britain. Womersley (1959) suggests that the species was probably spread by ships.

5.3 Influence of Artifically Heated Waters

Localities in low latitudes where warm effluents have eliminated native food fish and shellfish species may offer interesting opportunities for replacing these with desirable exotics that can tolerate the imposed temperatures (Walford and Merriman, 1970). To justify the effort in any locality, the area heated must be large enough to guarantee survival through the cold season. Although, as far as we know, the possibilities of bringing in food organisms from remote regions to enrich "thermally polluted" localities have been neither explored nor exploited, a number of invertebrates have been accidentally introduced, probably by ships. Naylor (1965) in a tabulation of accidental introductions into temperate European coastal waters, has marked those that have flourished in heated localities (Table 3).

TABLE 3

SOME WARM STENOTHERM SPECIES INTRODUCED BY HUMAN AGENCY INTO TEMPERATE EUROPEAN COASTAL WATERS (From Naylor, 1965)

Species	Introduced locality	Native locality
Kamptozoa:		
Loxosomella kefersteinii (Claparède)	*/ Swansea, S. Wales (Ryland & Austin, 1960)	E. Mediterranean & Red Sea
Polyzoa:		
Bugula neritina (Linnaeus)	*/ Plymouth, Devon (Marine Biological Assen., 1957) */ Shoreham, Sussex (Crisp & Molesworth, 1951) */ Swansea, S. Wales (Ryland, 1960; Naylor, 1965) */ Milford Haven, S. Wales (Ryland, 1960)	Sub-tropical areas
Polychaeta:		
Hydroides incrustans Monro	*/ Shoreham, Sussex (Monro, 1938) */ Swansea, S. Wales (Naylor, 1965; Gee, 1963)	Unknown (see Gee, 1963)

cont'd/..

Species	Introduced locality	Native locality
cont'd/..		
Mercierella enigmatica Fauvel	*/ Introduced to several British and European localities where it thrives best in areas of fluctuating salinity and slightly elevated temperatures (Fauvel, 1922; Monro, 1924; Tebble, 1953, 1956; Naylor, 1959, 1965; Markowski, 1962; Gee, 1963; Rasmussen, 1958)	Probably Indian Ocean (see Gee, 1963)
Nereis succinea Leuckart	*/ Possibly introduced by ships to various slightly estuarine localities (Smith, 1963), including a heated dock (Naylor, 1965)	S. Europe, spreading northwards (Smith, 1963)
Mollusca:		
Mercenaria (= Venus) mercenaria L.	Various European localities (Heppel, 1961) including Southampton Water where it flourishes near heated outfalls (Ansell, 1963a).	N. America
Crassostrea angulata	Various European localities	Sub-tropical areas
Crassostrea virginica	Various European localities	Eastern N. America
Crustacea:		
Penilia avirostris Dana	North Sea plankton (Cattling and Harding, 1949)	Sub-tropical and tropical coasts
Limnoria tripunctata Menzies	/ South and West Britain, breeding particularly in heated localities (Eltringham and Hockley, 1958; Jones, 1963; Naylor, 1965)	Widespread in temperate-tropical areas (Menzies, 1957)
Balanus eburneus Gould	From ship fouling in Britain (Bishop, 1951)	Caribbean to Massachusetts, USA and more recently Mediterranean and Bay of Biscay
Balanus amphitrite var. denticulata Broch	*/ Several British localities affected by heated effluents (Crisp and Molesworth, 1951; Naylor, 1965)	Sub-tropical areas
Processa aequimana Paulson	*/ Larvae in North Sea plankton (Rees and Cattley, 1949)	Mediterranean and Red Sea
Rhithropanopeus harrisi Gould	Several localities in N.W. Europe, including a heated part of Copenhagen Harbour (Wolff, 1954; Rasmussen, 1958)	N. America

cont'd/..

Species	Introduced locality	Native locality
cont'd/..		
Pachygrapsus transversus Gibbs	Various records in N.W. Europe (Bertelson and Ussing, 1936; Bull, 1962)	Sub-tropical areas
Pilumnus perlatus (Poeppig)	Plymouth, Devon (Marine Biological Assen., 1957)	S. America
Neopanope texana savi (Smith)	*✓ Swansea, S. Wales (Naylor, 1960)	N. America
Brachynotus sexdentatus (Risso)	*✓ Swansea, S. Wales (Naylor, 1957a, b)	Mediterranean
Callinectes sapidus (Rathbun)	Occasionally in N.W. Europe (Wolff, 1954)	N. and S. America
Pisces:		
Atherina boyeri (Risso)	*✓ A possible imported species in a heated dock at Swansea, S. Wales (Bowers and Naylor, 1964)	Mediterranean

(* Artificially heated localities; ✓ Breeding recorded)

5.4 Introductions with Oyster Plantings

Oyster culture, a practice going far back into antiquity in both the Orient and Occident, is responsible for the transfer of many species of organisms from one region to another. It is questionable that oyster culture surpasses the shipping industry in this respect, nevertheless, oysters as well as other epibenthic molluscs, do provide substrata for benthis organisms, which settle on their shells during infant stages. In its native habitat, an oyster is an essential part of a community of species. Beginning with its earliest spat stage through its life it becomes infested with sessile organisms that attach to or bore into its shells and compete with it for food; and parasites that feed in its shell cavity or its tissues. It is susceptible to disease and is the principal prey of many species of predators. Thus a serious risk is taken every time oysters are moved from one area to another. People have often discounted this risk in their enthusiasm to introduce what appears to be a species that might enrich their own native fauna.

In many instances, spat of a desired exotic oyster are brought into an area year after year simply to grow. Such an operation may be profitable in spite of the fact that unfavourable temperature and perhaps other properties of environments may prevent the introduced oysters from regular reproduction. Knowledgeable oyster growers take the utmost care to inspect and clean the spat in every shipment before planting. In some places, government inspectors examine all importations. Unfortunately, accidents do happen. In spite of precautions, an occasional shipment escapes the inspection, or undesired organisms in early stages of development pass through the inspection. Even though the oysters can't reproduce, their passengers may succeed spectacularly, living on or competing with the native fauna.

For example, the slipper limpet (Crepidula fornicata) is native to the eastern seaboard of North America from New Brunswick and Prince Edward Island in Canada to the Caribbean Islands and perhaps as far as Uruguay. It was carried to the Pacific (Chapman and Banner, 1949) and to northern Europe where it now occurs on all the coasts of England, Wales, France,

Belgium, Holland, Germany and Sweden (Walne, 1956). Although the slipper limpet seems to be non-competitive with oysters, its presence in quantity, according to Walne, results in an accumulation of mud resulting from their faeces and pseudo-faeces; and the bottom consequently becomes unsuitable for oyster culture (Walne, op. cit.). Moreover, dead limpet shells become reservoirs of infection for a serious fungal disease which affects shells of oysters (Korringa, 1951). The slipper limpet was introduced with shipments of oysters to the west coast of North America during the last century. It has been reported as established in San Francisco Bay and the vicinity.

Among the most destructive of the invertebrate animals preying upon oysters as well as other sessile animals are boring snails, called oyster drills, drill borers or whelk tingles. These marine snails, of which there are many species, infest oyster beds all over the world and are likely to be brought into any new area into which oysters are introduced. Since the spat stage of drills is not pelagic, it is most likely that the dispersal of these species is greatly facilitated by the transplanting of oysters. To cite a few examples: the American oyster drill, Urosalpinx cinerea, a west Atlantic species occurring naturally from Massachusetts Bay to Florida has been widely distributed with plantings of the eastern American oyster Crassostrea virginica. In the last decade of the 19th century it became established on oyster beds in western America and in northern Europe.

Another species, Ocenebra japonica, was introduced to Puget Sound, western North America, with shipments of the Pacific oyster from Japan. It was reported in 1939 as established as far south as Willapa Bay, Washington, and in 1964 as far north as Ladysmith Harbor, British Columbia. This drill is extremely destructive to oyster beds (Quayle, 1964).

The eastern mud snail, Nassarius obsoletus, was introduced with the eastern American oyster and is well established in Boundary Bay, British Columbia. It is also found in Wallapa Harbor, Washington, and San Francisco Bay, California (Quayle, 1964).

A Japanese snail, Battilaria cumingi, is among the most abundant of introduced species in British Columbia. Its distribution is associated directly with plantings of Japanese oysters. It is common in Boundary Bay, Ladysmith Harbor, and Crofton, Fanny and Cornox Bays.

The Atlantic green crab, Carcinides maenas, which attacks young oysters, was observed on the west coast of North America in Willapa Bay in 1961. The conch, Busycon canaliculatus, native to the western North Atlantic, has been introduced into San Francisco Bay, perhaps with plantings of eastern oysters. An anemone, Diadumene luciae, was introduced to the west coast of North America, presumably with Japanese oysters. It feeds on small crustacea and annelids (Ricketts and Calvin, 1962 ed.).

A parasitic copepod, Mytilicola orientalis, introduced with western Pacific oysters from Japan, has been established along the United States Pacific coast, where it infests native and exotic oysters and clams as well as other molluscs, including crepidula (Chew, et al, 1964).

Still another species of oyster drill, Purpura clovigera, was introduced to the west coast of North America with plantings of oysters from Japan. This was found in 1951 confined to a small area in Ladysmith Harbor, British Columbia (Quayle, 1964).

Another species of oyster, Crassostrea rivularis, was evidently introduced accidentally into Toten Inlet, Washington U.S.A. sometime before 1950 along with plantings of O. gigas.

A bay mussel, Modiolus demissus, was introduced unintentionally into San Francisco Bay, California, late in the 19th century with plantings of Crassostrea virginica. It has been established there enough to become an important food item to shore birds. It is also harvested in limited quantities for market (Hanna, 1966).

Another mussel, Modiolus senhousei, has been introduced unintentionally into San Francisco Bay and Tomales Bay, California, and Samish Bay, Puget Sound, Washington (Hanna, 1966), presumably along with spat of Crassostrea gigas from Japan.

A number of invertebrate animals of New Zealand origin have become established in Tasmania, presumably as a result of oyster, Ostrea angasi, plantings. These include two species of sea stars, Patiriella regularis and Astrostole scabra; two crabs, Cancer novozelandiae and Halicarcinus inominatus, a brachiopod, Terebratula rubicunda (Terebratula inconspicua); and several molluscs, Amaurochiton glaucus, Mytilus canaliculus, Maoricolpus roseus, Paphirus largillierti and Neilo australis. (Dartnall, 1969).

5.5 Introduction of Clams

A beneficial side effect of planting exotic oysters has been the occasional introduction of clams. Thus the soft clam, Mya arenaria, which occurs naturally in the North Atlantic from the Arctic Ocean to Cape Hatteras, North America, and to northwest Europe, was introduced into California with shipments of the eastern oyster early in the 1870's, and first reported as established in California in 1874. By 1880 it had spread to Willapa Bay, Washington, and in the course of several decades extended its range north to at least as far as Juneau, Alaska and south to Monterey Bay, California (Quayle, 1964; Fitch, 1953). In California it "is highly esteemed for food and the object of extensive sport and commercial fisheries. In years past this species was cultivated to a limited extent in the San Francisco Bay area." (Fitch, 1953).

A clam of the western Pacific, Tapes philippinarum, occurring naturally between 25° and 45° N latitude, was evidently unintentionally introduced to the Pacific coast of North America with plantings of oyster spat from Japan. It was observed first in Ladysmith Harbor, British Columbia in 1936. Within five years it had become so well established and abundant as to enter into the commercial catch. By the early 1960's it had established breeding populations in San Francisco Bay and Humboldt Bay, California, and Grays Harbor and Puget Sound, Washington, as well as in British Columbia (Quayle, 1964). In 1955 the California Department of Fish and Game transplanted the species to Morro Bay, where it has survived and prospered (Hanna, 1966).

Trapezium liratum, a clam of the western Pacific, has become established in most of the Pacific oyster growing localities (Solem, 1954; Hanna, 1966). It presumably accompanied shipments of C. gigas.

Meretrix lusoria, a western Pacific clam, planted in Humboldt Bay, California in 1957, and in Gray's Harbor, Washington in 1959, evidently failed to reproduce in either place. However, there seems to have been an accidental successful introduction of this species at Nash Harbor, Nunivak Island, Alaska. It may have been brought there on a Japanese schooner which was wrecked on the island a few years before 1927 (Hanna, 1966).

The quahog or hard clam, Venus mercenaria, native to eastern North America from Nova Scotia to Yucatan (Smith, 1940) may have been accidentally introduced into Humboldt Bay, California, in the 19th century with a planting of eastern oysters. There it may have established a small local population. Unfortunately, the identity of the species is uncertain. Since shellfish dealers ship the quahog from the east coast to the west and hold them in receivers for long periods, the species has the opportunity of becoming well established if conditions of environment permit (Fitch, 1953).

Shipments of quahog from Milford, Connecticut, were planted in California Bays in the 1960's - Humboldt Bay in 1960 and Drakes Estero and Tomales Bay in 1963. Survival was reported as good in 1966. In 1963 other plantings were made in Morro Bay and San Francisco Bay and experiments were being conducted towards establishing the species in Puget Sound, Washington (Hanna, 1966).

The quahog has also been introduced into various localities of Europe, evidently partly by deliberate attempts to establish the species, beginning at least as far back as the early

1870's, and partly by accident, most likely via the galleys of transatlantic vessels (Fretter and Graham, 1962; Ansell, 1963). Populations have become established in France, Holland, Belgium and Britain (Heppell, 1961). In Britain, the quahog is established throughout Southampton water, and has been recorded from Portsmouth Harbour and the Newtown Estuary, Isle of Wight. Animals exposed to warm effluents such as from generating stations grow faster, come into condition earlier in the season, and reach a higher spawning potentiality earlier than those elsewhere (Ansell, 1963). Walne and Dean have concluded from the results of experiments, that the larvae of the "quahog can be reared in substantial numbers, and the spat can be cultured with only moderate losses. The spat can be planted in the sea and our investigations show that there are a number of places in England and Wales where satisfactory growth and survival can be obtained." (See also pages 10 and 11 regarding introduction of clams to Hawaii).

Gemma gemma, a minute clam of eastern North America, has become established from Puget Sound to San Diego (Hanna, 1966). It was probably planted unintentionally with eastern oysters.

Petricola pholadiformis, a clam native to eastern North America, has become established in San Francisco Bay, California, and Willapa Bay, Washington (Hanna, 1966), probably unintentionally introduced with plantings of Crassostrea virginica.

5.6 Introduction by Aquarists

Lachner, et al. (1970) recount the introduction into Florida, U.S.A., of the walking catfish, Clarias batrachus, or pla duk dam (a Thai name). It occurs naturally from India to the Philippines, where it lives in swamps, ditches, canals, lakes and rivers. Albinos of this species have long been popular among home aquarists in the United States. Somehow, specimens were liberated into southern Florida waters a few years ago, probably from out-door holding ponds of local aquarium dealers. They reproduced successfully, and since Florida has many inter-connecting man-made waterways, and the walking catfish is not restricted to water but can travel by land, especially during damp or rainy nights, and tolerates salt water as well as fresh, it has become well-established from Fort Lauderdale northward to Lake Okeechobee and West Palm Beach, Florida. It has been found commonly in parts of the inter-coastal waterway in Palm Beach county. Its occurrence in the Miami area is apparently the result of separate releases. The walking catfish is an aggressive feeder, and out-competes native food and game species of superior value. There is no current American market for its flesh.

6. CONCLUSIONS

It seems probable, a priori, that in most instances an exotic species could succeed only at some expense to the populations of native species. If from a human viewpoint it has qualities which are superior to those of the affected native species, the introduction is beneficial. A number of qualities must be taken into account in considering which ones are superior, such as edibility, marketability, gaminess, as well as rates of fecundity, survival, growth, and so forth. People may consider an introduction valuable if it simply increases the variety or quantity of sea food at their disposal.

The successful establishment of an exotic species is probably irrevocable. Thus it would be ideal if the ecological consequences of any proposed introduction could be accurately predicted. Two questions must be considered with every proposed introduction: 1) what is the likelihood that the species can establish a self-sustaining population? 2) if it does become established, how will it affect the present value of sea food production? It is probably too much to expect dependable answers to these questions. The best we can do in each case is to consider all of the possible effects which we can conceive of, and then try to reach a carefully weighed judgment. More reliance might be put on answers to the first than to the second of these questions; for the principal basic necessities of the species to be introduced can fairly easily be discovered if they are not already known - the regimens of temperature and salinity, abundance of food, extent of suitable habitat, etc., such as required for survival,

growth and successful reproduction. If these necessities can be satisfied in the new environment, the probability of survival would seem auspicious, provided the conditions attending the shipment and planting are favorable.

In considering the second question, we must deal with the problems of defining value. What value do we seek from the introduction? More pounds of protein? An item for the luxury market? A new species to increase the variety of food or game fish and shellfish? A bait fish?

It is highly improbable that one could predict with any useful degree of accuracy how much or in what direction an introduction changes the sea food production or ecology in any area. Nor is there any basis of determining what the total catch of sea food in a given area might be now if there had been no introductions in the past. We have found records of a marine exotic causing the diminution of a native species but never of their absolute extinction. We assume that the least biological effect of past introductions has been to diversify the species composition in the areas affected. Thus the additions of exotic fish and shellfish have enriched the variety of sea food in California and Hawaii. We cannot judge how much it has affected the total biota in either place.

All of the intentional introductions of which we have found records are coastal, estuarine or anadromous species. Therefore our conclusions apply only to such forms. We assume that the distribution of a species is determined chiefly by the upper and lower limits of its temperature tolerance; by a long enough period in which the ambient temperature is conducive to reproduction; and by the presence of suitable habitat. In its native range it reaches its maximal abundance where its required conditions of environment are optimal. It is essential that the physical properties of the new environment correspond sufficiently with those of the original ones to provide the necessities for survival and reproduction. The more closely these properties approach optimal levels for a species and the longer they persist at those levels during a year, the more impressive is the success. This is all in agreement with principles described by Zenkevich (1952) and Karpevich (1960).

Introductions have failed when species have been planted in an area where the extremes of temperature exceed their limit of tolerance, where there is no place for them to take refuge while these extremes prevail, where other environmental necessities are not fulfilled, or where no available ecological niche exists. We have found no example of a species becoming "acclimatized" in the sense of adapting to a climate where extremes of temperature occur that would have been lethal in its original range.

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